

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NASA GENERAL WORKING PAPER NO. 10 054

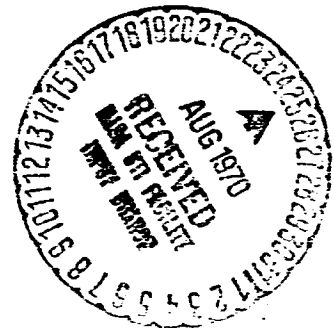
COMPUTER PROGRAM TO PREDICT THE NEWTONIAN
AERODYNAMICS OF GENERAL BODIES APPROXIMATED BY FLAT PLATES

FACILITY FORM 602

N70-35621
(ACCESSION NUMBER)
26
(PAGES)
TMX-64431
(NASA CR OR TMX OR AD NUMBER)

(THRU)
1
(CODE)
01
(CATEGORY)

[REDACTED]



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

August 11, 1965

NASA GENERAL WORKING PAPER NO. 16 064

COMPUTER PROGRAM TO PREDICT THE NEWTONIAN
AERODYNAMICS OF GENERAL BODIES APPROXIMATED BY FLAT PLATES

Prepared by:

Ralph E. Graham
Ralph E. Graham
AST, Aerodynamics Branch

Robert H. Lamb
Robert H. Lamb
AST, Aerodynamics Branch

Paul O. Romere
Paul O. Romere
AST, Aerodynamics Branch

Authorized for Distribution:

Warren Gillespie, Jr.
for Maxime A. Faget
Assistant Director for Engineering and Development

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

August 11, 1965

CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	1
SYMBOLS	2
DERIVATION OF EQUATIONS	4
APPLICATION OF THEORY	7
EXAMPLE	8
APPENDIX	9
Program Description	9
Program Input	10

LIST OF TABLES

Table		Page
I	EXAMPLE OF 25° CONFIGURATION	14
II	HYPERSONIC AERODYNAMIC COEFFICIENTS FOR GENERAL BODY	15

FIGURES

Figure		Page
1	Orientation of a unit normal vector of a flat plate segment to the principal axes and principal planes	16
2	Signs of the direction cosines of a unit normal directed towards the origin as a function of octant location	17
3	Orientation of unit velocity vector to body axes system	18
4	Coefficient sign convention	19
5	Example configuration	20
6	Predicted aerodynamics for example configuration . . .	21

COMPUTER PROGRAM TO PREDICT THE NEWTONIAN
AERODYNAMICS OF GENERAL BODIES APPROXIMATED BY FLAT PLATES

By Ralph E. Graham, Robert H. Lamb, and Paul O. Romere

SUMMARY

Equations for computing the Newtonian aerodynamics of a body composed of flat plate segments have been derived and incorporated into a digital computer program. A complete description of the computer program is included, and the use of the program is demonstrated by predicting the Newtonian aerodynamics of an example configuration consisting of four flat plates.

INTRODUCTION

The hypersonic aerodynamics of a three-dimensional shape can be approximated by Newtonian impact theory if the body is divided into a sufficient number of flat plates. The purpose of this report is to present the derivation of the equations defining the Newtonian aerodynamics of a general body composed of flat plate segments and to present a digital computer program which utilizes these equations. No attempt is made to compute the effects of the shading of a segment due to the presence of an upstream segment.

SYMBOLS

a, b, c	angles between the unit normal and the X-, Y-, and Z-axis, respectively
A, B, C	cosine of angles a, b, and c, respectively
C_A	axial-force coefficient, $\frac{-F_X}{qS_{ref}}$
C_D	drag coefficient, $\frac{F_D}{qS_{ref}}$
C_L	lift coefficient, $\frac{F_L}{qS_{ref}}$
C_l	rolling-moment coefficient, $\frac{M_X}{qS_{ref}D}$
C_m	pitching-moment coefficient, $\frac{M_Y}{qS_{ref}D}$
C_N	normal-force coefficient, $\frac{-F_Z}{qS_{ref}}$
C_n	yawing-moment coefficient, $\frac{M_Z}{qS_{ref}D}$
C_p	pressure coefficient, $\frac{P - P_\infty}{q}$
C_Y	side-force coefficient, $\frac{F_Y}{qS_{ref}}$
d, e, f	angles between the projection of the unit normal into the YZ plane and the Y axis, the XY plane and the X axis, and the XZ plane and the X axis respectively measured from the axis to the projection
D	reference length
Dx, Dy, Dz	cosine of angles a, b, and c, respectively

F_D	drag force
F_L	lift force
F_X	force along X-axis
F_Y	force along Y-axis
F_Z	force along Z-axis
$\vec{i}, \vec{j}, \vec{k}$	unit coordinate vectors
J, K, L	projection of the unit normal into the XY, XZ, and ZY planes, respectively
L/D	lift-drag ratio, C_L/C_D
M_X	rolling moment
M_Y	pitching moment
M_Z	yawing moment
$\frac{\vec{n}}{ \vec{n} }$	inward directed unit vector normal to surface
p	local pressure
p_∞	free-stream pressure
q	free-stream dynamic pressure
S	area
$\frac{\vec{V}}{ \vec{V} }$	unit wind vector
X, Y, Z	Cartesian body coordinate axes
$\Delta X, \Delta Y, \Delta Z$	transfer distances along X-, Y-, and Z- axis, respectively
α	angle of attack, deg
β	angle of sideslip, deg

η angle between unit normal and unit wind vectors, deg
 ϕ angle of roll, deg

Subscripts:

loc local area of each flat plate
 ref reference area

DERIVATION OF EQUATIONS

In order to determine the Newtonian aerodynamics of a flat plate segment, the angle η between the normal to the segment and the relative wind must be established. It has been found that the best way to determine this orientation is to use the angles which the normal to the segment makes in the principal planes (XY, XZ, and YZ planes). Figure 1 presents a unit normal vector at arbitrary angles to the principal axes and principal planes.

From a three view drawing of a flat plate segment any two of the three angles d, e, and f may always be determined. From figure 1, since $\tan d = \frac{C}{B}$; $\tan e = \frac{B}{A}$; and $\tan f = \frac{C}{A}$ then:

$$\frac{C}{B} = \frac{C/A}{B/A}$$

or

$$\tan d = \frac{\tan f}{\tan e}$$

Thus, knowing any two angles, the third angle may be determined.

The vector equation of the unit normal may be written

$$\frac{\vec{n}}{|\vec{n}|} = D_x \vec{i} + D_y \vec{j} + D_z \vec{k} \quad \text{where } D_x, D_y, \text{ and } D_z \text{ are the direction cosines.}$$

From figure 1, D_x thus represents the cosine of angle a, D_y the cosine of b, and D_z the cosine of angle c. It now remains to determine angles a, b, and c knowing angles d, e, and f. Again from figure 1

$$\frac{A}{J} = \cos e$$

$$J = \sin c$$

$$A = \sin c \cos e$$

$$\frac{B}{A} = \tan e$$

$$\frac{B}{\tan e} = \sin c \cos e$$

$$\sin c = \frac{\cos b}{\cos e \tan e}$$

therefore

$$\sin e = \frac{\cos b}{\sin c}$$

but since

$$\frac{C}{B} = \tan d = \frac{\cos c}{\cos b}$$

$$\sin e = \frac{\cos c}{\sin c \tan d}$$

or

$$\tan c = \frac{1}{\sin e \tan d}$$

also since

$$\tan f = \frac{\cos c}{\cos a}$$

$$\cos a = \frac{\cos c}{\tan f}$$

similarly

$$\cos b = \frac{\cos c}{\tan d}$$

Thus all the direction cosines have been determined in terms of the angles the projections of the unit normal into the three principal planes make with the principal axes. It should be noted that the above

relations are valid only for angles less than or equal to 90° . If the unit normal lies in other octants, the correct signs must be given to the cosine of angles α , β , and γ . Figure 2 shows the numbering of the octants along with the proper signs for the direction cosines of a unit normal vector lying in any octant and directed towards the origin.

The vector equation of the relative wind at the Euler angles of α , β , and ϕ to the axes system may be written after inspection of figure 3.

$$\frac{\vec{V}}{|\vec{V}|} = -\cos \alpha \cos \beta \vec{i} - (\sin \alpha \cos \beta \sin \phi + \sin \beta \cos \phi) \vec{j} + (\sin \beta \sin \phi - \sin \alpha \cos \beta \cos \phi) \vec{k}$$

The normal force coefficient of a flat plate is defined by Newtonian theory as

$$C_N = 2 \cos^2 \eta$$

The angle η may be found by taking the dot product between the unit normal vector and the unit velocity vector

$$\frac{\vec{n}}{|\vec{n}|} \cdot \frac{\vec{V}}{|\vec{V}|} = \left| \frac{\vec{n}}{|\vec{n}|} \right| \left| \frac{\vec{V}}{|\vec{V}|} \right| \cos \eta = \cos \eta$$

Thus

$$\cos \eta = Dx(-\cos \alpha \cos \beta) - Dy(\sin \alpha \cos \beta \sin \phi + \sin \beta \cos \phi) + Dz(\sin \beta \sin \phi - \sin \alpha \cos \beta \cos \phi)$$

The C_N contribution of a segment to the C_N of the total body can be expressed as

$$C_N = 2 \cos^2 \eta \frac{S_{loc}}{S_{ref}} (-Dz)$$

where S_{loc} is the local area (segment area) and S_{ref} is the reference area. (See figure 4 for coefficient sign convention.) Although the C_A and C_Y of a flat plate are zero in Newtonian theory, the flat plate C_N may be resolved into the body axis system to produce both coefficients.

$$C_A = 2 \cos^2 \eta \frac{S_{loc}}{S_{ref}} (-Dx)$$

and

$$C_Y = 2 \cos^2 \eta \frac{S_{loc}}{S_{ref}} (Dy)$$

The moment coefficients may be written:

$$C_m = C_N \frac{\Delta X}{D} - C_A \frac{\Delta Z}{D}$$

$$C_l = -C_Y \frac{\Delta Z}{D} - C_N \frac{\Delta Y}{D}$$

$$C_n = C_Y \frac{\Delta X}{D} + C_A \frac{\Delta Y}{D}$$

where the signs of the transfer distances (ΔX , ΔY , and ΔZ) are taken as positive when the direction from the body moment reference center to the segment centroid is in the positive axis direction. The reference length is D .

APPLICATION OF THEORY

In applying the theory, consideration must be given to the problem of shading. In Newtonian theory, it is assumed that the flow travels a straight path; there is no curvature of the flow around a body. Thus, it is possible for a body segment to partially or completely shield or shade a down stream body segment from the flow, resulting in zero force on the shielded segment. Since no provision has been made in the previous relations to account for this shading, each segment must be considered in the presence of the total body for each attitude the body makes with the wind to determine if shading occurs.

In approximating the surface of the desired body by using flat plate segments, an important aspect to be considered is the local curvature of the surface. If the direction of the normal to the given surface segment to be replaced by a flat plate varies a great deal then the aerodynamics can be very incorrect. One example of the former is an attempt to replace a spherical segment by pie-shaped flat plates. The direction of the normal to the spherical segment pie-shaped wedge varies

considerably across the shape. The unit normal for the flat plate wedge yields a poor approximation to the actual aerodynamics. The correct approach is to choose the flat plate segments small enough so that no large change in normal direction will occur.

EXAMPLE

An example configuration consisting of four flat plates is presented in figure 5 to demonstrate the program's use. Included in the figure are the unit normal projections for one of the flat plate segments to illustrate the methods of measuring the angles d , e , and f . The predicted aerodynamics of the example configuration are presented in figure 6.

APPENDIX

Program Description

The method set forth on the previous pages has been programed for a digital computer so that the Newtonian aerodynamics of a flat plate or a group of flat plates which approximate a general configuration may be computed. The shading or flow - see boundary due to Newtonian theory is calculated internally by the program. This is accomplished by testing the value of $\cos \eta$ for each flat plate. If this quantity is zero or negative, the coefficients for this flat plate are set equal to zero since the plate is shaded. Shading caused by upstream portions of the body must be handled externally to the program; that is, the section of the body which would be shaded by a protuberance is not read into the program. It should be noted that as either α , β , or ϕ change, this shading effect will be different.

For the convenience of the user, several options or unique features are provided and are as follows:

1. The user may either obtain the aerodynamics for each flat plate as well as for the total vehicle or may obtain the aerodynamics of only the total vehicle.
2. The user may vary the angles of attack, sideslip, or roll without restriction. There is no limit to the number of combinations that may be used.
3. The user may make configuration changes to the configuration without having to run a new case. An example of such a feature would be a configuration having flaps. The configuration could be run with one deflection through α , β , ϕ combinations; then the flap could be deflected to a new angle and the resulting configuration could be run back through all the same α , β , ϕ combinations.
4. The program also calculates six component derivatives with respect to either α or β . This is accomplished by perturbing either α or β 1° and assuming linearity.
5. If the vehicle is symmetrical about the XZ plane and is at zero angles of sideslip and roll, only half of the vehicle need be read in. The program will calculate values for the total vehicle.

Program Input

The following is a detailed description of the input cards and the options that may be used. Presented in table I is an example case of input for the configuration presented in figure 5.

Step 1 Title card

This is a hollerith card which may contain from 1 to 50 characters which describe the configuration being run.

Step 2 SREF, DXFormat 2F10.0

SREF = Reference area of configuration
DX = Reference length of configuration

Step 3 STPCOFormat F10.0

STPCO = Pressure coefficient

Step 4 J, JS, JL, JA, JBFormat 5I4

J = Total number of flat plate segments
JS Allows segment printout if 1
Allows only total configuration printout if 0
JL = Number of configuration changes desired
JA = Number of cards contained in step 6
JB If 1, it is a symmetrical body and only half of the configuration is read in, but the total aerodynamics are calculated
If blank, total body is read in

NOTE: If JB is set equal to 1, β and ϕ must equal 0

Step 5

E(1)	D(1)	F(1)	X(1)	Y(1)	Z(1)	SLOC(1)	KKK(1)
.
.
.
E(J)	D(J)	F(J)	X(J)	Y(J)	Z(J)	SLOC(J)	KKK(J)

E(I) - Angle measured in the XY plane from the X axis toward the Y axis

D(I) - Angle measured in the YZ plane from the Y axis toward the Z axis

F(I) - Angle measured in the XZ plane from the X axis toward the Z axis

X(I) - X transfer distance

Y(I) - Y transfer distance

Z(I) - Z transfer distance

NOTE: The sign of the transfer distance is taken as positive when the direction from the body moment reference center to the segment centroid is in the positive axis direction

SLOC(I) - Local reference area of the segment

KKK(I) - This is the value of the octant in which the unit normal lies and ranges from 1 - 8.

The following should be noted:

1. Angles E(I), D(I), and F(I) must be between 0° and 90°. It should be noted that only 2 of the 3 angles are needed. If one cannot be determined, set that angle equal to 400.0° and the program will calculate the value internally.

2. Format - (7F10.0;I2)

3. The octant of the unit normal may be defined as follows:

Octant = 1 if unit normal lies in +X, +Y, +Z
 Octant = 2 if unit normal lies in -X, +Y, +Z
 Octant = 3 if unit normal lies in -X, -Y, +Z
 Octant = 4 if unit normal lies in +X, -Y, +Z
 Octant = 5 if unit normal lies in +X, +Y, -Z
 Octant = 6 if unit normal lies in -X, +Y, -Z
 Octant = 7 if unit normal lies in -X, -Y, -Z
 Octant = 8 if unit normal lies in +X, -Y, -Z

Step 6 ALPHT, BETAT, PHIT Format 3F10.0

ALPHT = α at which aerodynamics are desired

BETAT = β at which aerodynamics are desired

PHIT = ϕ at which aerodynamics are desired

It should be noted that each card counts as one toward calculating JA in step 4.

If JL equals zero, this ends the input; however, if JL has a value, the following steps are needed:

Step 7 KK, J1, J2, J3, J4, J5, J6 Format 7I4

KK equals 0 if only six or less segments are being changed
 equals 1 if more than six segments are being changed
 J1 - identification number of first segment being changed
 J2 - identification number of second segment being changed
 J3 - identification number of third segment being changed
 J4 - identification number of fourth segment being changed
 J5 - identification number of fifth segment being changed
 J6 - identification number of sixth segment being changed

In step 5, the first flat plate read in is given an internal identification number of 1 and each succeeding plate an identification number one greater until all values are read in. Therefore, to find the correct identification for this step, the user need only go to step 5 and determine what plate is being changed and its identification number.

NOTE: If only one segment is being changed, J2 through J6 are left blank.

Step 8

E(J1)	D(J1)	F(J1)	X(J1)	Y(J1)	Z(J1)	SLOC(J1)	KKK(J1)
.
.
.
E(J6)	D(J6)	F(J6)	X(J6)	Y(J6)	Z(J6)	SLOC(J6)	KKK(J6)

NOTE: If, for example, only two changes are made only 2 cards would be read in in this step.

Step 9

If KK = 0 this ends input

If KK = 1 repeat steps 7 and 8

It should be noted that for all changes which have been made in steps 7 and 8, the program will then repeat all α , β , and ϕ variations that were input in step 6.

An example output is shown in table II. The first portion of the output consists of the title of the case and is followed by the calculated

direction cosines and the input quantities for each segment, the transfer distances, the segment area, and the angles which the normal to the segment make. These are printed out in the order in which they were input. The calculated aerodynamic coefficients consisting of the force coefficients C_A , C_Y , and C_N and the moment coefficients C_l , C_m , and C_n are presented as C_A , C_Y , C_N , and C-ROLL, C-PITCH, and C-YAW. Also presented are the aerodynamic force and moment derivatives with respect to sideslip (β) and angle of attack (α).

TABLE II.- HYPERSONIC AERODYNAMIC COEFFICIENTS FOR GENERAL BODY

DERIVATIVES ARE IN DEGREES FOR THE TOTAL VEHICLE
EXAMPLE 25 DEG CONFIGURATION

THE INPUT WAS AS FOLLOWS

DCX	DCY	DCZ	X	Y	Z	SLDC
-0.112521E-00	-0.419934E-00	0.900552E 00	-0.413000E 01	0.150000E 01	-0.145000E 01	0.617400E 02
-0.112521E-00	-0.419934E-00	-0.900552E 00	-0.413000E 01	0.150000E 01	0.145000E 01	0.617400E 02
-0.112521E-00	0.419934E-00	-0.900552E 00	-0.413000E 01	-0.150000E 01	0.145000E 01	0.617400E 02
-0.112521E-00	0.419934E-00	0.900552E 00	-0.413000E 01	-0.150000E 01	-0.145000E 01	0.617400E 02
ANGLE E						
0.750000E 02	ANGLE D					
0.750000E 02	ANGLE F					
0.750000E 02	0.400000E 03					
0.750000E 02	0.400000E 03					
0.750000E 02	0.400000E 03					

ALPHA = 0.500000E 01

BETA = 0.

PHI = -0.

L/D = 0.448332E 01

CL = 0.460072E-01

CD = 0.102619E-01

REFERENCE AREA = 0.167500E 03 REFERENCE LENGTH = 0.166670E 02 PRESSURE COEF. = 0.200000E 01

LA		CY		CN	
C-ROLL	C-PITCH	C-YAW	C-ROLL	C-PITCH	C-YAW
0.621302E-02	0.873115E-10	0.467265E-01	0.621302E-02	0.873115E-10	0.467265E-01
0.409273E-11	-0.120865E-01	-0.181899E-11	0.409273E-11	-0.120865E-01	-0.181899E-11
0.159293E-04	-0.203424E-02	-0.142315E-04	0.159293E-04	-0.203424E-02	-0.142315E-04
-0.150490E-03	0.368129E-05	0.553130E-03	-0.150490E-03	0.368129E-05	0.553130E-03
0.882092E-03	-0.845830E-10	0.921988E-02	0.882092E-03	-0.845830E-10	0.921988E-02
0.522959E-11	-0.238486E-02	-0.454747E-11	0.522959E-11	-0.238486E-02	-0.454747E-11

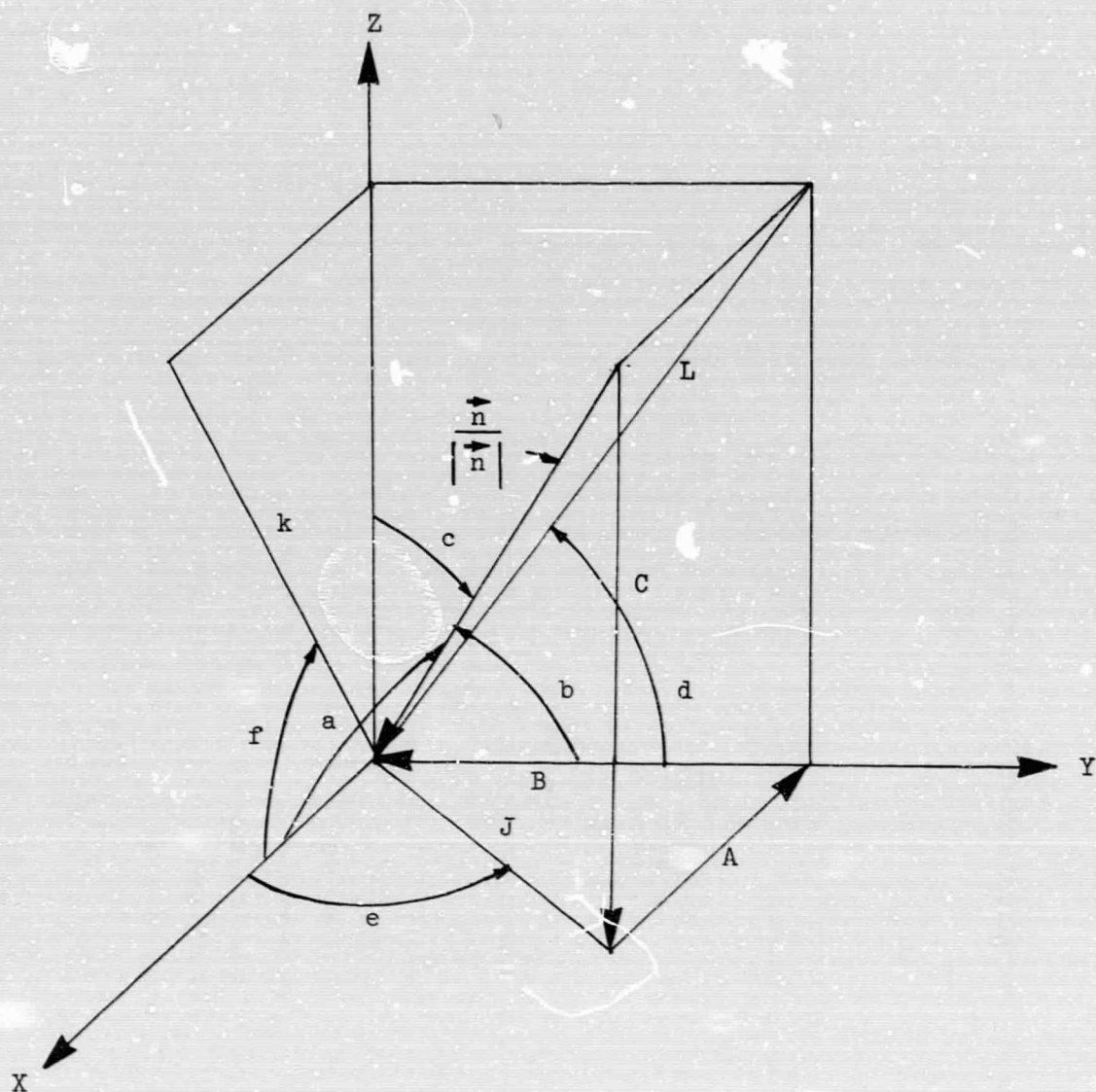
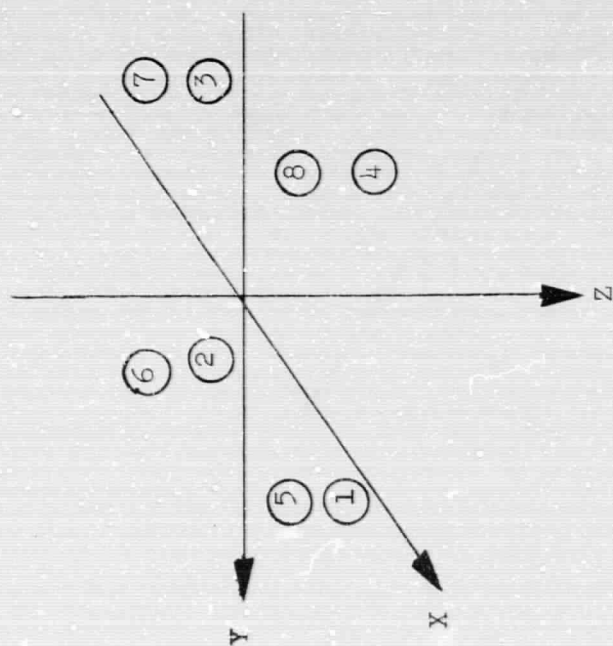


Figure 1.- Orientation of a unit normal vector of a flat plate segment to the principal axes and principal planes.



Octants 1, 2, 3, and 4 have positive Z
 Octants 5, 6, 7, and 8 have negative Z

Figure 2.- Signs of the direction cosines of a unit normal directed towards the origin as a function of octant location.

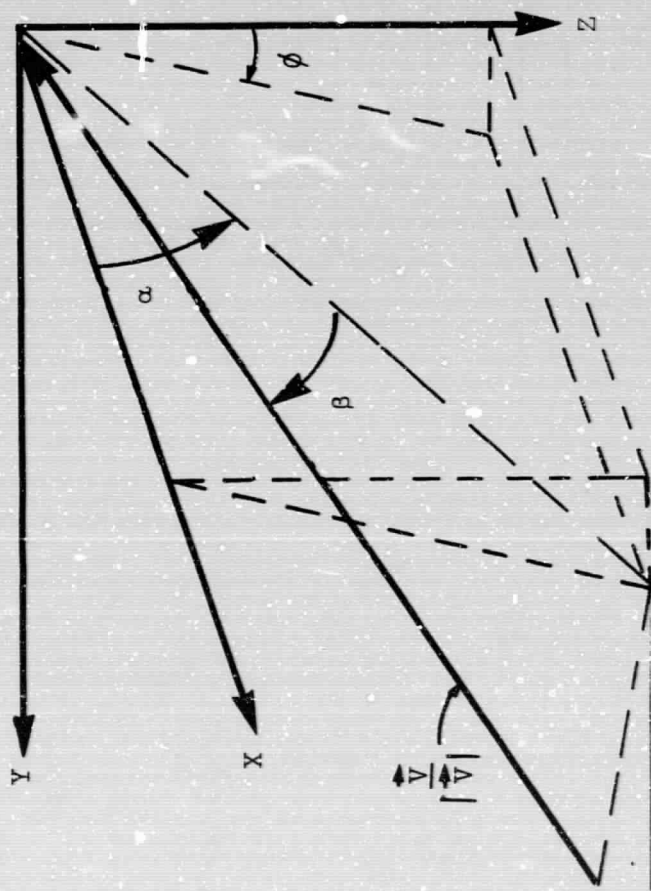


Figure 3.- Orientation of unit velocity vector to body axes system.

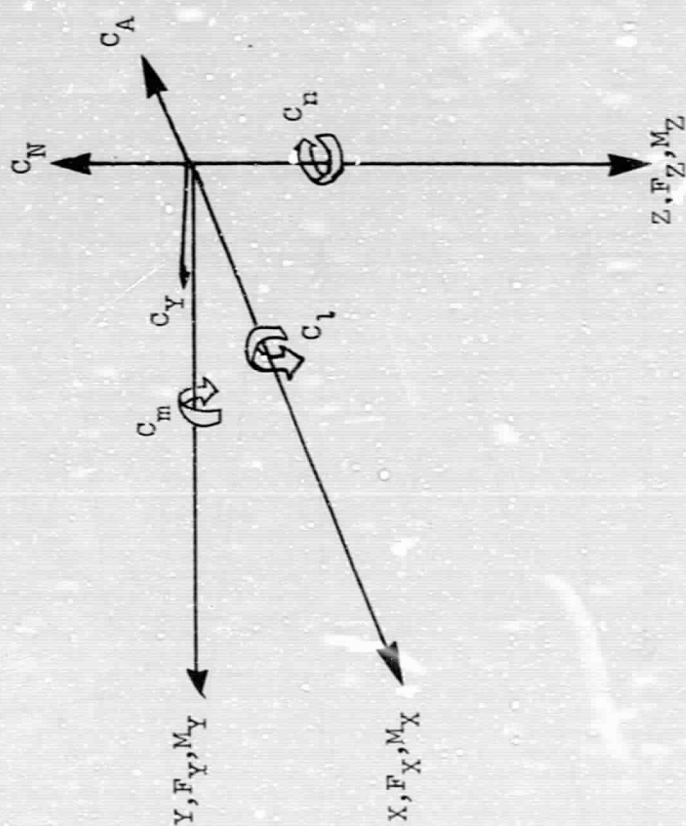


Figure 4. - Coefficient sign convention.

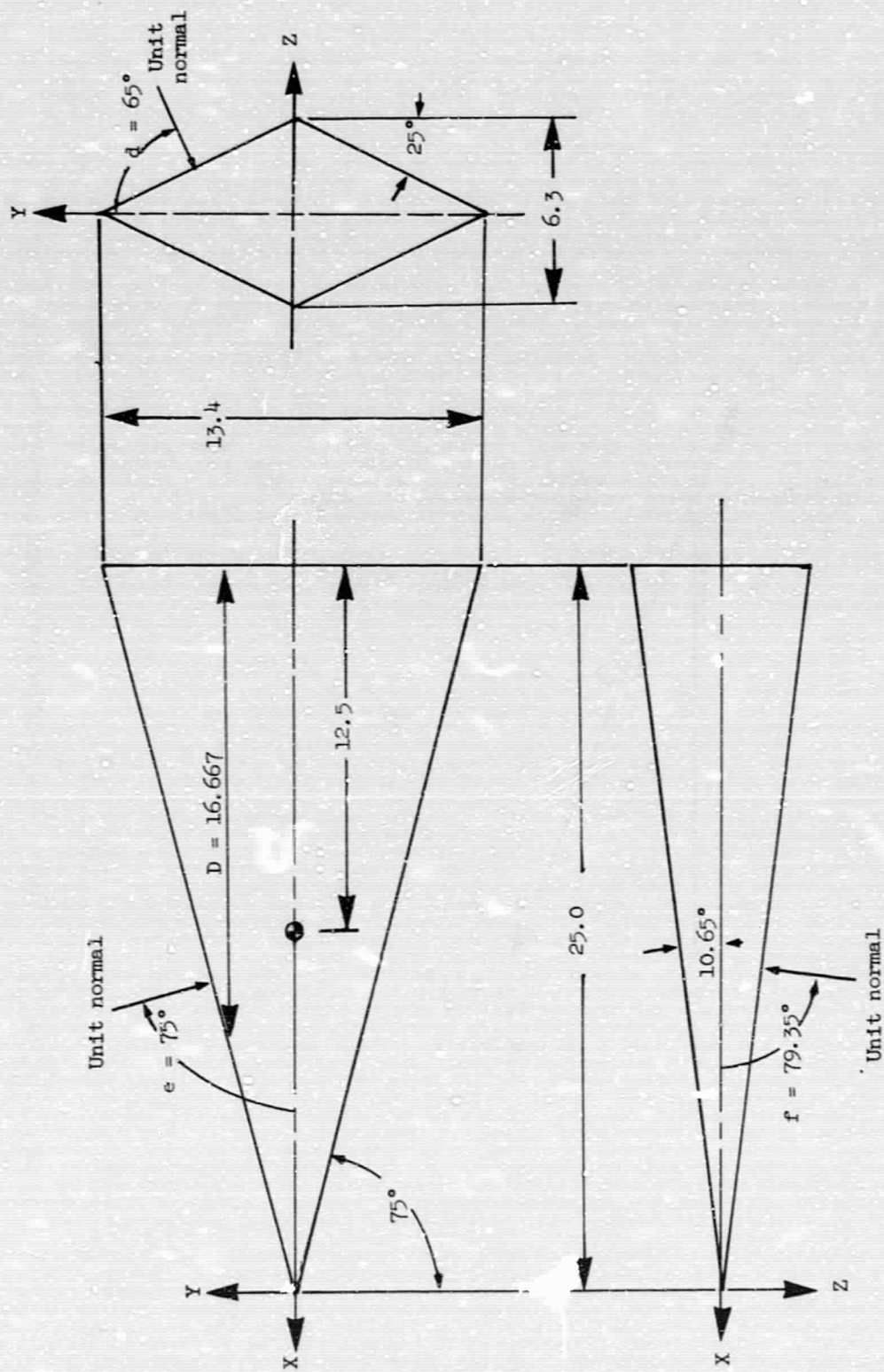


Figure 5.- Example configuration.

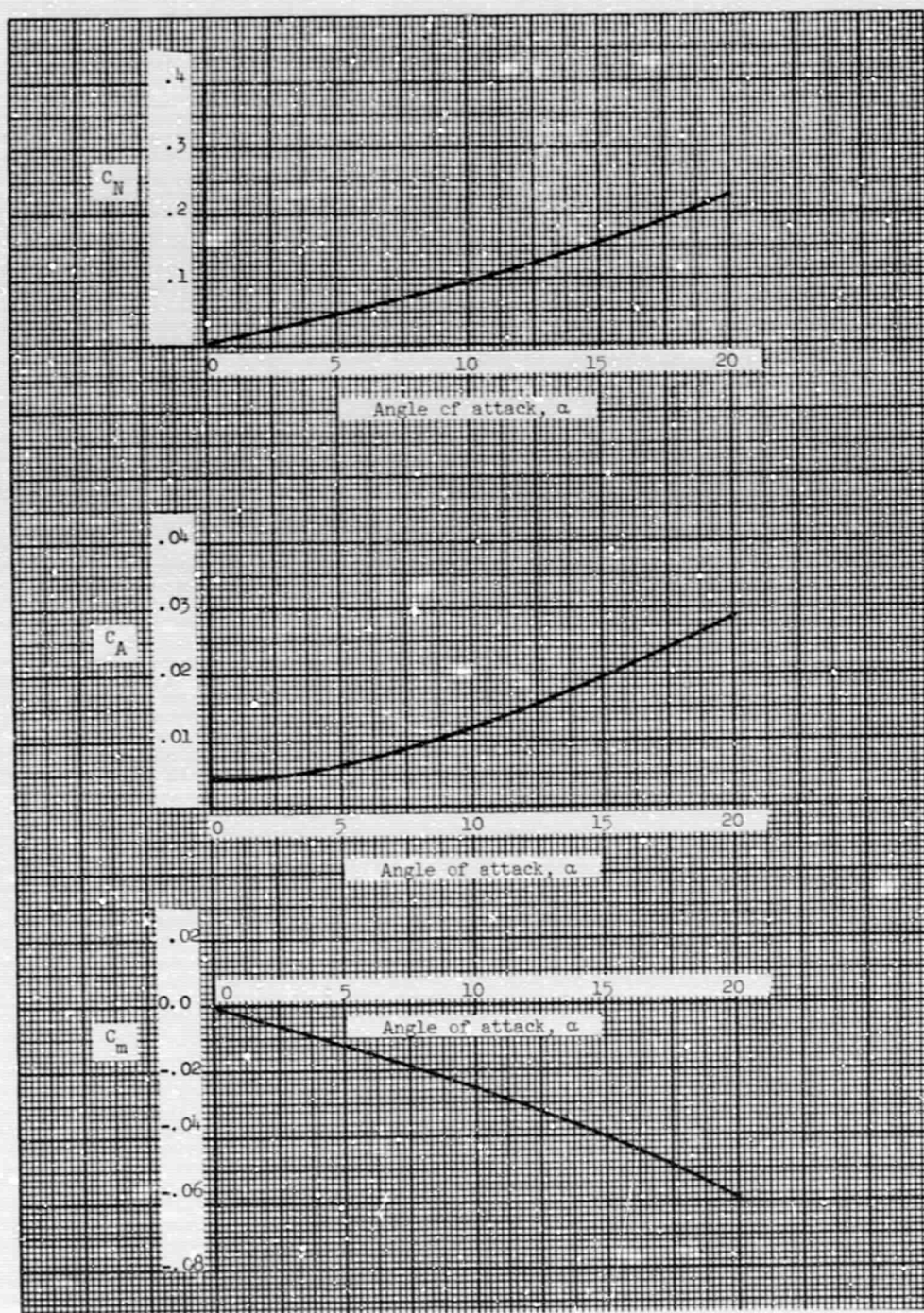


Figure 6. - Predicted aerodynamics for example configuration.

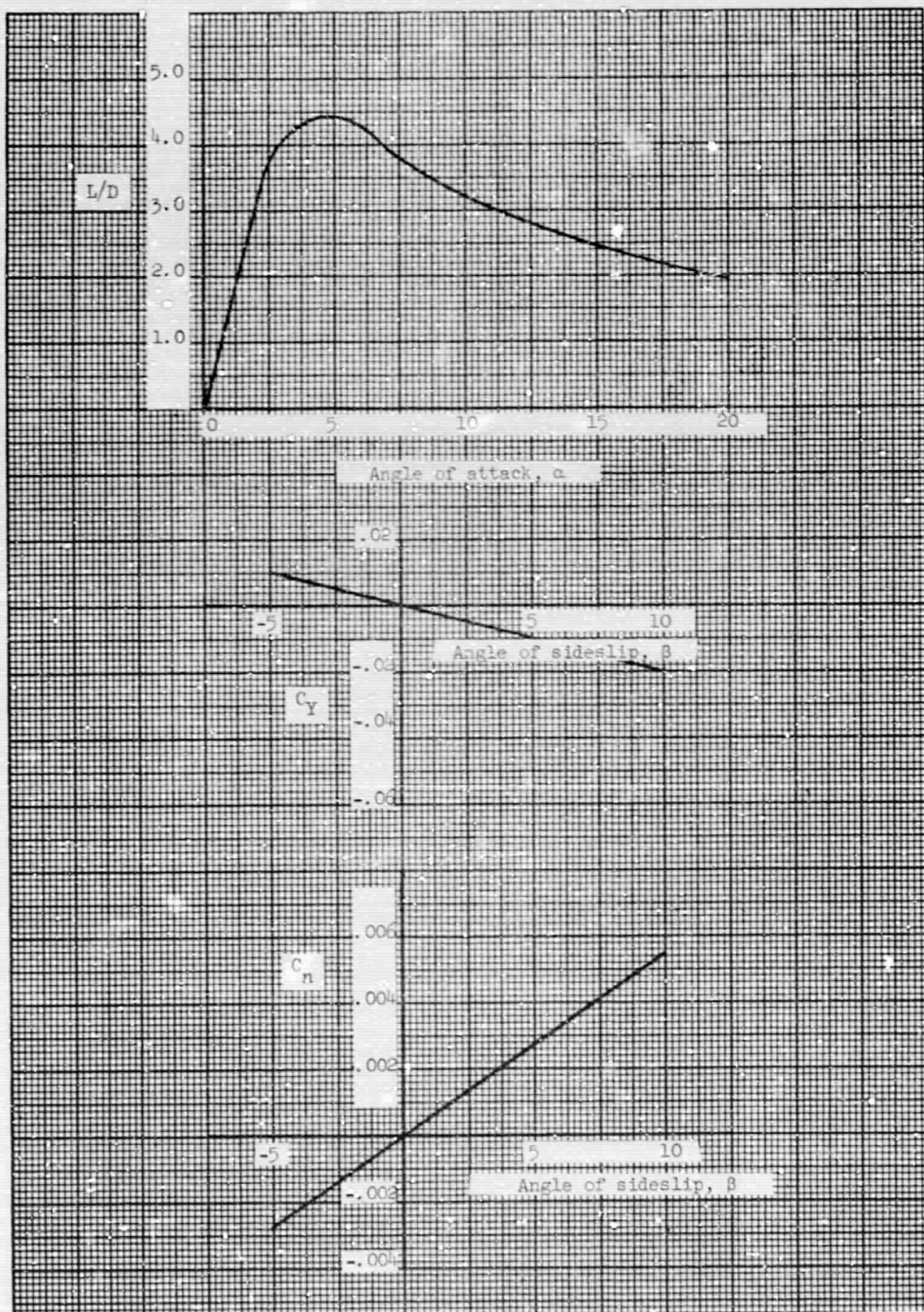


Figure 6.- Concluded